The Limits of Competition in Defense Acquisition
Defense Acquisition University Research Symposium, September 2012

Keywords: acquisition, game theory, competition, bidding strategy, pricing

The Effects of Competition on Defense Acquisitions

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Abstract

As defense acquisition costs have soared over the past decade, efforts at reforming the acquisition system have focused intensely on creating more opportunities for competition as a means to reduce costs and incentivize better contractor performance. While competition can, in some cases, reduce costs and improve contractor performance, it is not a cure-all for the problems that plague defense acquisitions. This paper presents a quantitative approach, using game theory to model the effects of competition on contractor pricing. It demonstrates that the way in which a competition is structured can be a determining factor in whether competitive pressure is sufficient to balance the additional development costs of multiple contractors and higher unit costs from splitting the award. Specifically, the way contractors are incentivized to bid (or not bid) depends on the number of rounds of competition, the number of units awarded in each round, and the split in award between the winner and loser for each round. The analysis reveals that in some instances the structure of the competition can actually incentivize contractors to bid higher and drive up costs.

Summary

The way a competition is structured can be a determining factor in whether competitive pressure is sufficient to balance the additional development costs of multiple contractors and the higher unit costs from splitting the award in defense acquisitions. In some instances, the structure of the competition can actually incentivize contractors to bid higher and drive up costs.

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14. ABSTRACT
As defense acquisition costs have soared over the past decade, efforts at reforming the acquisition system have focused intensely on creating more opportunities for competition as a means to reduce costs and incentivize better contractor performance. While competition can, in some cases, reduce costs and improve contractor performance, it is not a cure-all for the problems that plague defense acquisitions. This paper presents a quantitative approach, using game theory to model the effects of competition on contractor pricing. It demonstrates that the way in which a competition is structured can be a determining factor in whether competitive pressure is sufficient to balance the additional development costs of multiple contractors and higher unit costs from splitting the award. Specifically, the way contractors are incentivized to bid (or not bid) depends on the number of rounds of competition, the number of units awarded in each round, and the split in award between the winner and loser for each round. The analysis reveals that in some instances the structure of the competition can actually incentivize contractors to bid higher and drive up costs.

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"Competition is a major source of productivity in the defense industry, as it is in commercial industry." –Former Secretary of Defense Robert Gates

"Real competition is the single most powerful tool available to the Department to drive productivity." –Former Under Secretary of Defense Ashton Carter

In a free market-oriented society, competition is often advanced as a sound way to achieve cost savings. As defense acquisition costs have continued to soar over the past decade, efforts to reform the acquisition system have focused intensely on creating more opportunities for competition, both to reduce costs and to incentivize better contractor performance. The Weapon Systems Acquisition Reform Act of 2009, for example, requires the Department of Defense to use acquisition strategies that "ensure competition, or the option of competition, at both the prime contract level and the subcontract level." The law goes on to specifically identify competitive prototyping and dual-sourcing as measures to ensure competition. While competition, in some cases, can reduce costs, promote innovation, and improve contractor performance, it is not a "cure-all" for the problems that plague defense acquisitions. Rather, the cure of competition can sometimes be worse than the disease.

The purpose of this paper is to develop an analytic framework for evaluating when competition can reduce acquisition costs and how best to structure a competition to drive down acquisition costs. This analysis focuses specifically on the use of dual-sourcing as a means of ensuring competition in the acquisition of major weapon systems. It uses a competitive pricing model that accounts for how companies will be incentivized to bid under different conditions. The analysis is limited to the acquisition costs of a program from development through procurement and does not evaluate the use of competition to encourage innovation or to reduce operational risk.

Background

One of the underlying reasons that competition does not always reduce costs in defense acquisitions is that the U.S. defense industry is not a traditional free market with many buyers and sellers and limited regulation. The defense industry can be more accurately characterized as a monopsony with the U.S. government as the sole customer and chief regulator. There are few (if any) other buyers for many of the major weapon systems DoD procures, such as stealthy aircraft, aircraft carriers, nuclear-powered submarines, and specialized communications and electronics equipment. Where there are other potential customers, such as allies and partner nations, sales must still be approved through the U.S. government and tend to be much lower in quantity. Moreover, in many sectors of the defense industry there are a limited number of vendors capable of producing the weapon systems DoD requires—just one or two primes in some sectors. In these instances, the defense market is a monopsony-duopoly (two vendors) or a bi-lateral monopoly (one vendor).

The defense industry's lack of free market characteristics is hardly a new phenomenon. As Milton Peck and Frederick Scherer noted in their 1962 analysis of defense acquisitions, two essential elements of a free market system are competitive pricing and buyers exerting control over sellers through patronage. But in the defense industry, prices are often based on the costs incurred by contractors, with DoD having detailed insight into the internal costs of companies. Moreover, DoD exerts control over sellers not just by patronage but also by being a regulator of the industry (Peck & Scherer, 1962, p. 582). DoD does not

just buy weapons, it sets the requirements for them and takes an active role in designing them. Peck and Scherer concluded that "the concepts of a market economy are not a fruitful point of departure for formulating weapons acquisition policy."

Jack Gansler picked up on the same theme in his 1982 book, *The Defense Industry*, listing 30 examples of how the defense market differs from a free market. For example, in traditional free-market theory, as demand falls prices fall. Yet in the defense market, as demand falls prices often rise. Moreover, in a free market, a buyer can choose to spend now or save for a later purchase, but DoD must spend its annual appropriation or risk losing those funds. Defense companies know this. Because the defense industry is not a traditional free market, it does not always respond as expected to free market incentives. Gansler (1982) concludes:

> It is proper to question policies that attempt to impose optimal free-market conditions piecemeal in individual cases or individual sectors… Yet through its various regulations and micro policies the Department of Defense has been applying small adjustments here and there in an attempt to create conditions closer to optimal free-market conditions, with neither an overall (sector by sector) policy coordination effort nor a recognition that *these actions might be making things worse*. [emphasis added] (p. 31)

Why Competition Does Not Always Reduce Costs

Three main factors can prevent competition from having the desired effect of reducing costs in defense acquisitions: the added cost of redundant development work, the learning curve effect, and the structure of the competition itself. The first two are relatively straightforward to analyze. As the only customer for many of the weapon systems it buys, DoD pays the full development cost for many of these systems through cost reimbursable development contracts or higher fees on fixed-priced contracts. In order to create an opportunity for competition, DoD must pay (directly or indirectly) for two or more contractors to develop the same system. This redundant development work adds to the overall program cost. Even if DoD pays for the development work only once and gives the same design to two or more companies for production (a "build to print" approach), it must still pay for the development of more than one production line.

Once development work is complete, DoD can down-select to a single vendor for production using a competitive process. This effectively ends the competition and grants the winner a monopoly for future procurements of the same system. Another option is to split the award between competing contractors to maintain the prospect of future competition. A split award, however, means that neither contractor receives as many orders and thus neither can progress as far down the learning curve as they could if only one firm were engaged in production. The learning curve effect, first quantified by researchers at Wright-Patterson Air Force Base in the 1920s, is the observed pattern that as more units of a particular item are built, whether airplanes, tanks, computers, or other systems, the production cost of each unit progressively declines (Reguero, 1957, pp. 213-214). The learning percent quantifies the slope of the learning curve.[1] For example, a learning percent of 85 means that each time the quantity of items built doubles the unit cost is 85 percent of what it was before, as shown in Figure 1. If a contract award is split between

[1] This analysis uses a specific-unit cost learning curve rather than a cumulative average cost learning curve.

contractors, neither will build as many units as they would under a single award. Thus, the cost of each unit will not decline as much as it would if one company were building all of the units.[2]

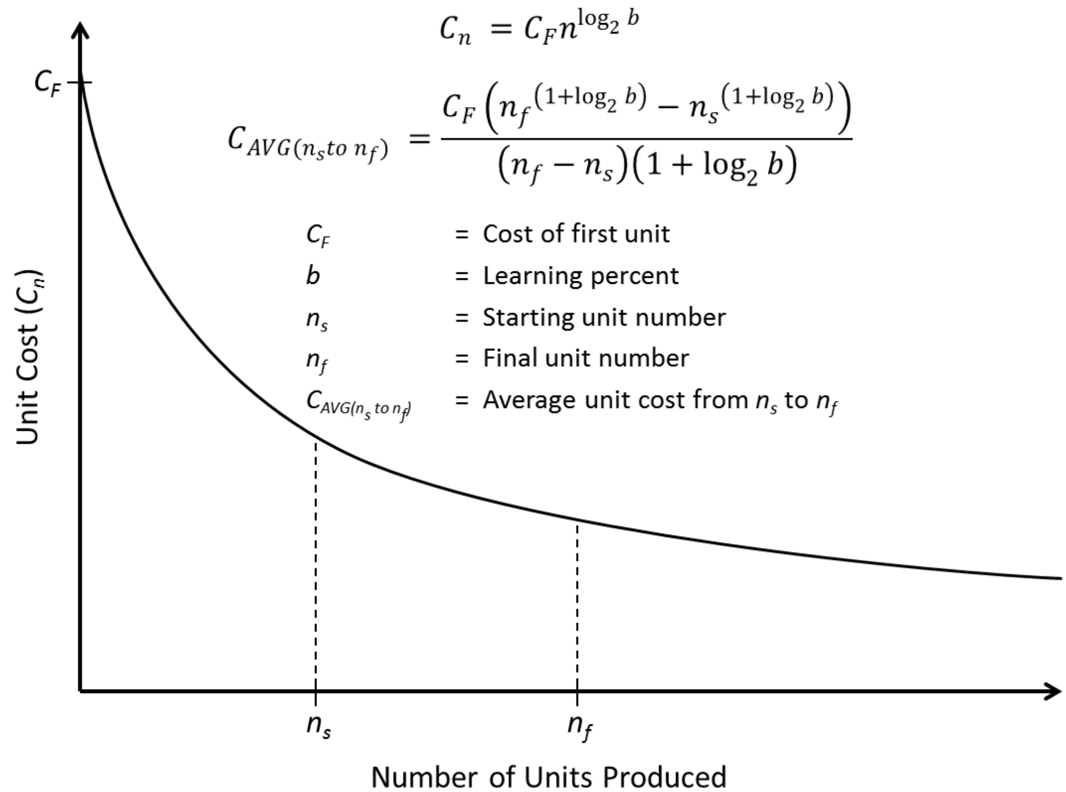

Figure 1: Example Learning Curve

Proponents of competition argue that these additional costs from redundant development work and reduced learning can be offset by the competitive pressure among contractors to drive down prices. For example, the Institute for Defense Analysis (IDA) estimated that a competitive procurement of the Joint Strike Fighter engine would reduce total procurement costs by 11 to 18 percent (Woolsey, 2008, p. 4). IDA's conclusion is based on analysis of two previous engine procurements in which dual sourcing was used, the F-100 engine used in the F-15 and F-16 fighters and the F-404 engine used in the F/A-18 fighter. Such historical data reveals what happened to costs in these programs when dual sourcing was used. But to calculate the savings from competition, one also needs to know what would have happened had dual sourcing *not* been used—something historical analysis cannot provide. Moreover, historical analysis does not account for how the structure of the current competition may fundamentally differ from the structure of previous competitions, such as differences in the split in award between the winning and losing contractors or differences in the quantity of units being procured. Historical analysis is, therefore, insufficient to fully understand the effects of competition on contractor pricing.

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[2] Some argue that the lack of competitive pressure may increase the learning percent for a sole-source contractor, thus reducing the savings achieved by awarding all of the units to one contractor. This hypothesis is difficult to test without conducting a controlled experiment in which both a sole-source contract and a competitive process are used in parallel for the same acquisition. The model presented in this paper can account for a potential difference in learning percent by using different values for the learning percent in the sole-source case and competitive cases.

This paper presents a quantitative approach, using game theory to model the effects of competition on contractor pricing. It demonstrates that the way in which a competition is structured can be a determining factor in whether competitive pressure is sufficient to balance the additional development costs of multiple contractors and the higher unit costs from splitting the award. The analysis reveals that in some instances the structure of the competition can actually incentivize contractors to bid higher and drive up costs. Six cases are used to explain how the model works and how it can be used to better shape acquisition strategy and determine when competition can help reduce acquisition costs.

Analysis

The following analysis uses a consistent set of assumptions based on a hypothetical acquisition program, shown in Table 1, applied in six different cases. In the first case, a sole-source acquisition is used to award all of the work to a single company. This provides a baseline for comparison of the alternative cases, each of which funds two development contractors to compete for production work. The alternative cases vary the structure of the competition by altering the split in award between the companies, the number of rounds of competition, and the quantity of units awarded in each round.

Table 1: Assumed Parameters for a Hypothetical Acquisition Program

First Unit Cost (C_F)	Learning Percent (b)	Maximum Profit (P_{max})	Minimum Profit (P_{min})	Total Quantity of Units Procured (Q)	Initial Development Cost (C_{DEV})
$1,000	85%	10%	-10%	100	$2,000

The alternative cases use a common set of assumptions:

- Competitors: The model assumes two competitors, Company A and Company B, that both produce products meeting all of the government's requirements (a "form, fit, and function" approach).[3] For the purposes of this analysis, the companies' products are assumed to have identical first unit costs, learning percent, and development costs, although these factors can be varied independently in the model. The model also assumes that in the event the two companies bid exactly the same price, Company A wins all ties.

- Perfect Information: The model assumes that both companies have perfect information about their own costs, such as first unit cost and learning percent, as well as their competitor's underlying costs. The model also assumes that the companies bid at the same time in secret so that one does not know how the other is bidding in the current round. The companies do, however, know how their competitor bid in previous rounds.

- Profit Maximizing: The model assumes that the companies will try to maximize their net profit from all rounds of competition, rather than maximize profit in a single round. This means that a company could, in theory, bid at a price below its own costs (i.e. lose money) in an early round on the hope that it could offset these losses with greater profit in later rounds.

[3] A form, fit and function approach means the government gives both contractors a set of technical data for the item being procured, and the contractors must build to these requirements.

- <u>Bidding Options:</u> In practice, each company has a virtually infinite number of prices it can bid in each round of competition. In order to constrain the analysis to a finite set of results, the model assumes each company has a limited set of six price points to select from in each round. These price points are determined dynamically in each round for each company according to the formulas shown in Table 2. For example, both Company A and Company B could bid a price that would result in zero profit if they win that particular round of competition, corresponding to option 4 in the table. If Company A has won more orders than Company B in previous rounds, it will have progressed further down the learning curve and its costs will be lower. Company A's zero-profit bid will therefore be a lower amount than Company B's zero-profit bid, and Company A will win the round. Two constants are assumed in the model to determine bid prices. P_{max} is the maximum rate of profit and P_{min} is the minimum rate of profit for each company.

Table 2: Summary of Bidding Options Used in Model

Bidding Options	Description	Formula
1: Max Profit If Loss	Bid price is the maximum rate of profit allowed, P_{max}, applied to the average unit cost, $C_{AVG\ (ns\ to\ nf)}$, assuming this round is lost and the company receives the smaller share of units awarded ($n_f = n_{lose}$). In most cases, this is the highest possible bid price in the model for a company in a given round.	$Bid = (1 + P_{max}) \times C_{AVG\ (n_s\ to\ n_{lose})}$
2: Max Profit If Win	Bid price is the maximum rate of profit allowed, P_{max}, applied to the average unit cost, $C_{AVG\ (ns\ to\ nf)}$, assuming this round is won and the company receives the larger share of units awarded ($n_f = n_{win}$).	$Bid = (1 + P_{max}) \times C_{AVG\ (n_s\ to\ n_{win})}$
3: Zero Profit If Loss	Bid price is the average unit cost, $C_{AVG\ (ns\ to\ nf)}$, assuming this round is lost and the company receives the smaller share of units awarded ($n_f = n_{lose}$).	$Bid = C_{AVG\ (n_s\ to\ n_{lose})}$
4: Zero Profit If Win	Bid price is the average unit cost, $C_{AVG\ (ns\ to\ nf)}$, assuming this round is won and the company receives the larger share of units awarded ($n_f = n_{win}$).	$Bid = C_{AVG\ (n_s\ to\ n_{win})}$
5: Min Profit If Loss	Bid price is the minimum rate of profit allowed, P_{min}, applied to the average unit cost, $C_{AVG\ (ns\ to\ nf)}$, assuming this round is lost and the company receives the smaller share of units awarded ($n_f = n_{lose}$).	$Bid = (1 + P_{min}) \times C_{AVG\ (n_s\ to\ n_{lose})}$
6: Min Profit If Win	Bid price is the minimum rate of profit allowed, P_{min}, applied to the average unit cost, $C_{AVG\ (ns\ to\ nf)}$, assuming this round is won and the company receives the larger share of units awarded. In most cases, this is the lowest possible bid price in the model for a company in a given round ($n_f = n_{win}$).	$Bid = (1 + P_{min}) \times C_{AVG\ (n_s\ to\ n_{win})}$

- Dominance: Based on the above assumptions, the model evaluates all possible combinations of bids by the two contractors over one or multiple rounds of competition.[4] For each possible outcome, the net profit of each contractor and the total cost to the government is calculated. Using the process of iterated elimination of strictly dominated strategies, outcomes that would never be pursued by profit maximizing companies can be eliminated (Murrow, 1994, pp. 98-99). For example, consider a single-round competition where two companies can either bid high or bid low. Suppose the profit earned by Company A from bidding high would be either $1,000 or $2,000, depending on how Company B bids, and Company A's profit from bidding low would be either $500 or $900, also depending on how Company B bids. Since Company A's profit is greater from bidding high regardless of how Company B bids, bidding high strictly dominates bidding low for Company A. Eliminating strictly dominated strategies narrows the set of outcomes to only those that are feasible given the assumptions used in the analysis.

- Implicit Assumptions: In the following examples, the unit cost is assumed not to vary with production rate or economies of scale. In reality, when an award is split between two contractors and each produces at a lower rate, costs will increase due to less efficient use of manufacturing resources and a possible loss of economies of scale.[5] The losing contractor in each case will also have fixed overhead costs that must be spread across a smaller number of production units. Because these higher costs are not included, the results will tend to make competition look more favorable (lower cost) than it should in some cases. The learning percent is also assumed constant throughout the production run, where in reality the rate of learning could vary over time. For simplicity, all costs are undiscounted and the production timelines are assumed to be similar for all cases.

Case 1: Sole-Source Award

The base case for comparison is a sole-source award of the development and procurement contracts with no competition. The total cost to the government using the relevant values assumed in Table 1 and assuming the contractor receives zero profit would be:

$$C_{TOTAL} = C_{DEV} + Q \times C_{AVG\ (0\ to\ Q)}$$

$$= \$2{,}000 + 100 \times \left(\frac{\$1{,}000 \times 100^{(1+\log_2 0.85)}}{100 \times (1 + \log_2 0.85)} \right) = \$46{,}372$$

Assuming the maximum rate of profit, 10 percent in this example, the total cost to the government would be:

$$C_{TOTAL} = C_{DEV} + Q \times (1 + P_{max}) \times C_{AVG\ (0\ to\ Q)}$$

$$= \$2{,}000 + 100 \times (1 + 0.1) \times \left(\frac{\$1{,}000 \times 100^{(1+\log_2 0.85)}}{100 \times (1 + \log_2 0.85)} \right) = \$50{,}809$$

Thus, the total cost to the government in the base case would be between $46,372 and $50,809 depending on what level of profit the contractor is able to negotiate in a sole-source award.

[4] For the purposes of this study, the author developed a custom piece of software to conduct the calculations required.

[5] Economies of scale capture a separate effect than the learning curve. Economies of scale typically become a factor when production is increased sufficiently to warrant a different manufacturing process. The learning curve effect, in contrast, represents the improved efficiency that results from repeating the same process more times.

Case 2: Single Round, Winner-Take-All

In a winner-take-all competition, DoD typically funds two or more contractors to develop prototype systems and holds a competition where a single winner receives the full production order. This approach is used in the acquisition of many major weapons systems, including the F-35 Joint Strike Fighter. If each company is limited to three bidding options: 10 percent profit, zero profit, and -10 percent profit (corresponding to options 2, 4, and 6 in Table 2).[6] Nine outcomes are possible, and of these nine, five are strictly dominated, meaning either one company or the other would never bid in this manner. The strictly dominated strategies in this example, denoted with an "X" in Figure 2, involve one or both companies bidding at a loss. It stands to reason that these bidding strategies would be strictly dominated in a single-round competition—why bid at a loss on a program with no hope of ever making back those losses? Using the same assumed values for development cost, first unit cost, and learning percent as in Case 1, the total cost to the government among the non-dominated strategies ranges from $48,371 to $52,808. Because the range of costs for the winner-take-all competition overlaps with the range of costs in Case 1 (sole-source), one cannot be certain which option will result in the best outcome for the government.

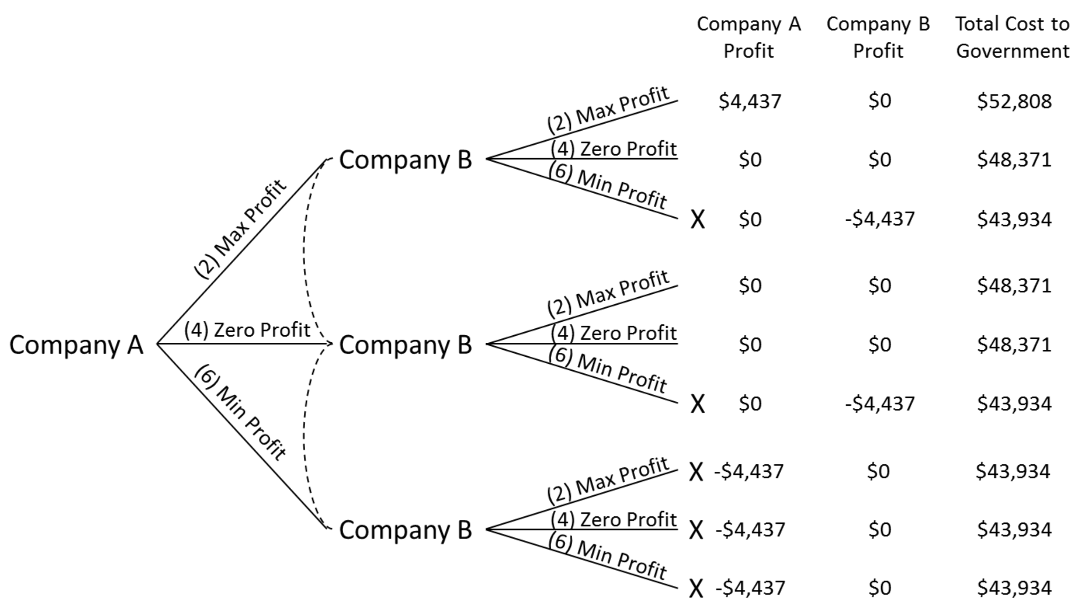
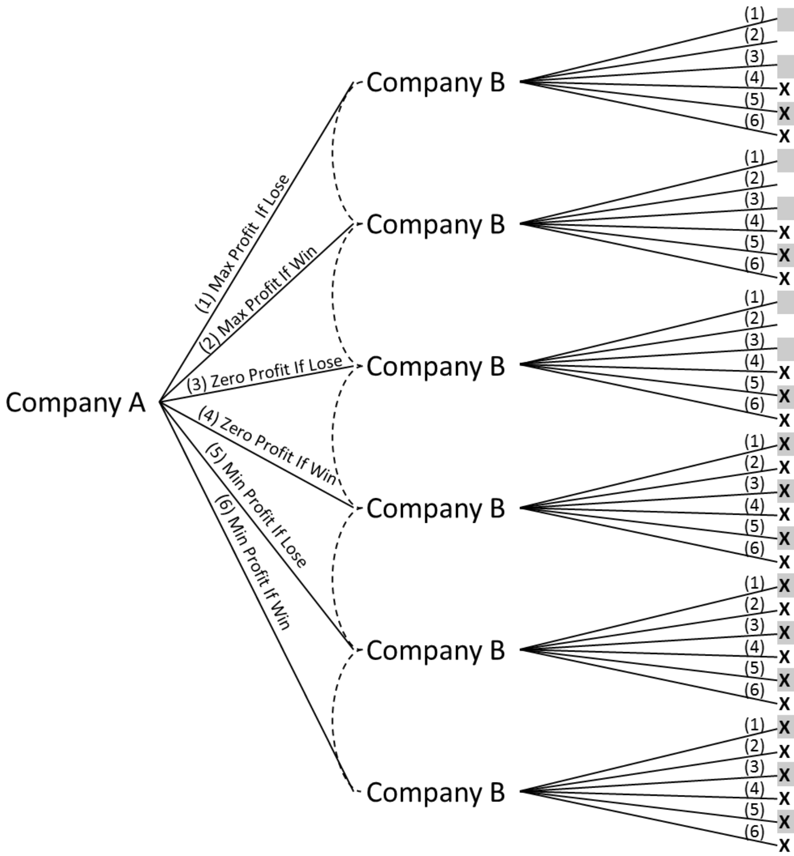


Figure 2: Game Tree Representation of Winner-Take-All Competition

Case 3: Single Round, Split Award

The results are significantly different if a split award is used instead of a winner-take-all approach. With a split award, each company can use all six of the bid options listed in Table 2, which means 36 different combinations of bids are possible. Under a single-round competition with a 60/40 split (the winner receives 60 percent of the order and the loser receives the remaining 40 percent), 27 of the 36 strategies are strictly dominated, as shown in Figure 3. Of the remaining nine non-dominated strategies, the total cost to the government ranges from $59,005 to $64,506 for a 60/40 split.

[6] For the winner-take-all case, three of the bid options previously shown in Table 2 (options 1, 3, and 5) are not possible because they are calculated based on the cost per unit if the company loses the round. In a winner-take-all competition, the losing company receives no orders, which would result in an undefined unit cost for these bid options.



Company A option	Company B option		Company A Profit	Company B Profit	Total Cost to Government
(1)	(1)		$6,293	$2,200	$64,506
(1)	(2)		$2,200	$3,001	$61,213
(1)	(3)		$2,200	$2,993	$61,205
(1)	(4)	X	$2,200	$0	$58,212
(1)	(5)	X	$2,200	-$307	$57,905
(1)	(6)	X	$2,200	-$3,001	$55,211
(2)	(1)		$3,001	$2,200	$61,213
(2)	(2)		$3,001	$5	$59,019
(2)	(3)		$5	$2,993	$59,011
(2)	(4)	X	$5	$0	$56,018
(2)	(5)	X	$5	-$307	$55,710
(2)	(6)	X	$5	-$3,001	$53,016
(3)	(1)		$2,993	$2,200	$61,205
(3)	(2)		$2,993	$5	$59,011
(3)	(3)		$2,993	$0	$59,005
(3)	(4)	X	$0	$0	$56,012
(3)	(5)	X	$0	-$307	$55,705
(3)	(6)	X	$0	-$3,001	$53,011
(4)	(1)	X	$0	$2,200	$58,212
(4)	(2)	X	$0	$5	$56,018
(4)	(3)	X	$0	$0	$56,012
(4)	(4)	X	$0	-$1,995	$54,017
(4)	(5)	X	-$1,995	-$307	$53,710
(4)	(6)	X	-$1,995	-$3,001	$51,016
(5)	(1)	X	-$307	$2,200	$57,905
(5)	(2)	X	-$307	$5	$55,710
(5)	(3)	X	-$307	$0	$55,705
(5)	(4)	X	-$307	-$1,995	$53,710
(5)	(5)	X	-$307	-$2,200	$53,505
(5)	(6)	X	-$2,200	-$3,001	$50,811
(6)	(1)	X	-$3,001	$2,200	$55,211
(6)	(2)	X	-$3,001	$5	$53,016
(6)	(3)	X	-$3,001	$0	$53,011
(6)	(4)	X	-$3,001	-$1,995	$51,016
(6)	(5)	X	-$3,001	-$2,200	$50,811
(6)	(6)	X	-$3,001	-$3,996	$49,015

Figure 3: Game Tree Representation of Single-Round, 60/40 Split-Award Competition

With all other factors held constant, as the split in award is increased the minimum cost declines and the maximum cost increases, as shown in Figure 4. In the 50/50 case the only non-dominated bidding option for both companies is that which yields the highest possible profit because they are guaranteed to win half the awards no matter what price they bid. If the split is increased to 55/45, only the two highest bidding options are non-dominated. With an 80/20 split four bidding options are non-dominated for both players (options 1, 2, 3, and 5 from Table 2), which makes the competition more robust and even creates the possibility of one contractor losing money.[7] The maximum cost under the 80/20 split is higher because if both companies bid the highest price possible the government will end up paying the losing contractor to build a small quantity at a high unit cost. The cost to the government for an 80/20 split ranges from $55,430 to $75,183, compared to a range of $46,372 to $50,809 for a sole-source award and $48,371 to $52,808 for a winner-take-all competition, as shown in Figure 4.

[7] In this example, using an 80/20 split, a contractor could lose money if it bids option 5, a -10 percent discount (loss) applied to a higher unit cost (assuming the round will be lost). If the contractor loses the round, it would therefore lose 10% of its actual costs. However, if the contractor wins the round it would make a profit because the actual unit cost would be much lower than unit cost assumed—a difference that would more than offset the -10% discount.

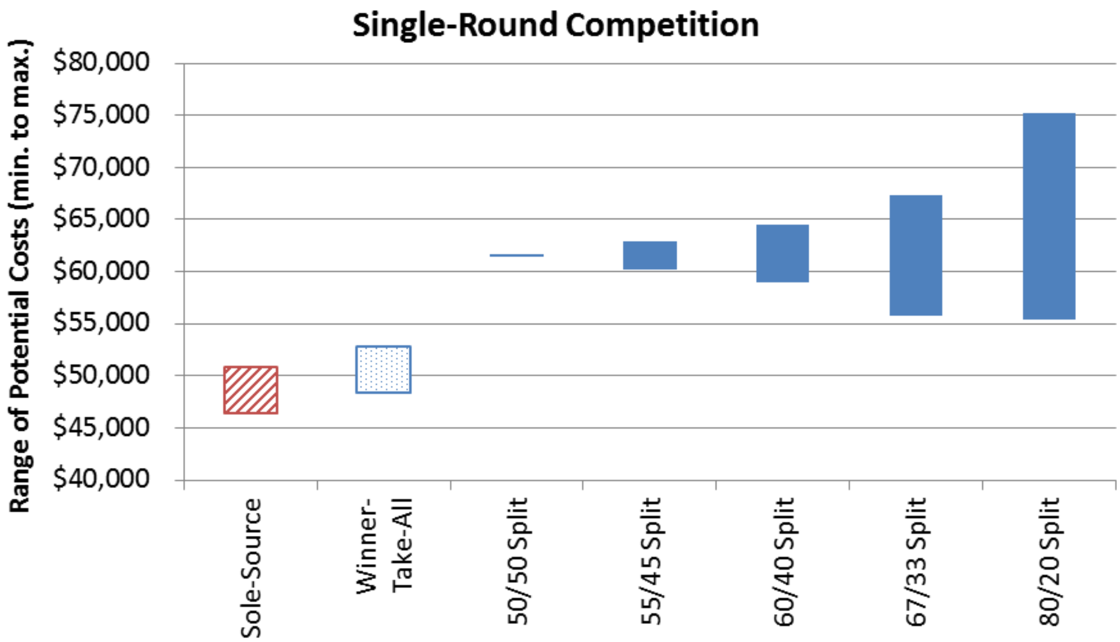


Figure 4: Comparison by Award Split for Single-Round Competition

Given the assumptions stated above, this example demonstrates that both the sole-source and winner-take-all competition are better for the government than a single-round, split-award competition. The total cost to the government is higher with a single-round, split-award competition no matter how the competitors bid among the range of non-dominated strategies and regardless of the split in award. Even if the companies bid at the maximum rate of profit allowed for both a sole-source award and a single-round, winner-take-all competition, a split-award competition will still cost more. This is due to the significant cost reductions that come from progressing further down the learning curve when all of the units are awarded to a single contractor.

Case 4: Multiple Rounds

More complex competitive bidding strategies begin to emerge when the competition is expanded to multiple rounds. The fourth case varies the number of rounds of competition, keeps the split in award constant across each round, and evenly divides the number of units awarded across each round. The game trees for multi-round competitions are not shown because they are too large, but the calculations use the same basic process as in a single-round competition. The number of possible outcomes grows exponentially with each additional round of competition, from 1,296 possible outcomes in a two-round competition to nearly 1.7 million possible outcomes in a four-round competition. For a three-round competition, the software developed for this analysis can compute the results for every possible outcome and determine which outcomes are strictly dominated within a few minutes. Four-round competitions generally require an hour or less to run. For a five-round competition, the number of possible outcomes exceeds 60 million and requires significant computational time to analyze (multiple days for each run), and thus lies beyond the scope of this paper. The results for one to four rounds of competition using 60/40, 67/33, and 80/20 award splits are shown in Figure 5.

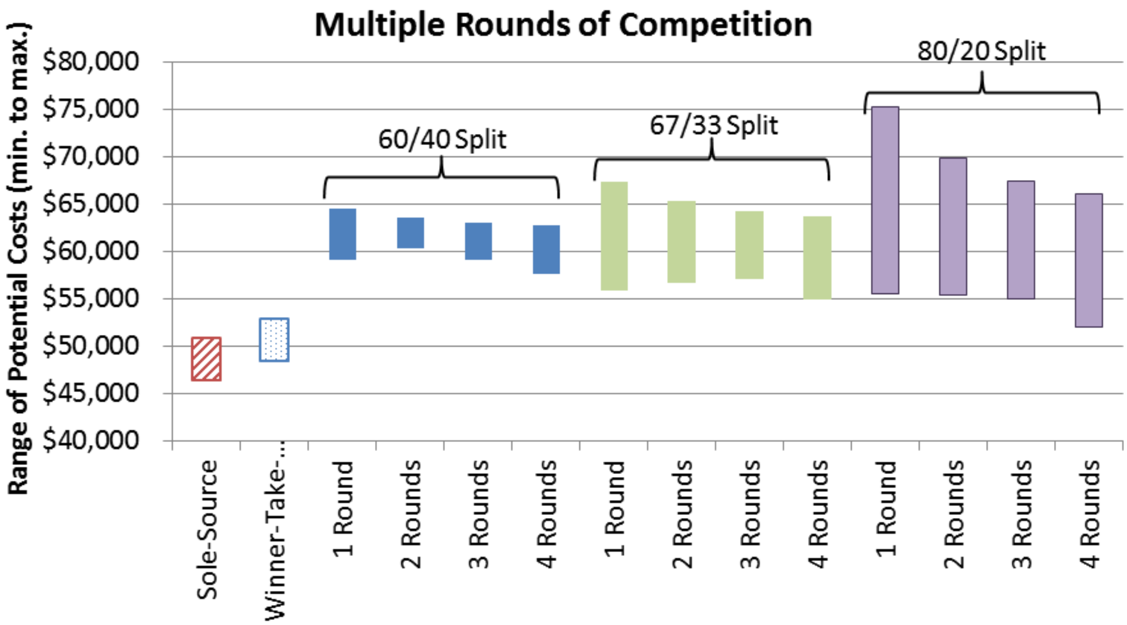


Figure 5: Multiple Rounds of Competition with Different Award Splits

As in a single-round competition, merely increasing the split in award in a multiple-round competition widens the range of potential costs to the government by increasing the maximum cost and lowering the minimum cost. As the number of rounds of competition is increased from one to four, the maximum cost to the government declines for a given award split. Under the set of assumptions used in this example, none of the ranges of potential costs overlap with the range of costs for a sole-source award for any of the combinations of award splits and number of rounds examined.

The reason for this becomes evident when examining the non-dominated bidding strategies that emerge from a multi-round competition. In the three-round, 80/20 split competition, for example, the only real competition occurs in the first move. The companies have a strong incentive to bid low and win 80 percent of the first order because the winner will progress significantly further down the learning curve than the loser and have a lower unit cost for bidding in future rounds. Thus, the company that loses the first round has a much higher unit cost going into the second round—so much that even if it bids the lowest possible price (a -10 percent discount if it wins) it is still not enough to overcome the price advantage of the other company. Because it cannot win future rounds and turn a profit, the only non-dominated bidding strategy for the company that loses the first round is to bid the highest possible price and maximize profits from the smaller award it will receive in the remaining two rounds. The company that wins the first round knows that bidding high is the only logical choice for its competitor, and thus it bids high as well in the final two rounds to maximize its profits. The competition essentially transitions from a race to the bottom in terms of price in round one, to a race to the top in terms of profit in rounds two and three.

Case 5: Multiple Rounds, Variable Award Split

One option to avoid the apparent futility of competition after the first round is to increase the stakes in later rounds of competition. The fifth case varies the split in award for each round while keeping the quantity of units awarded evenly divided across each round. The examples shown in Figure 6 compare

the range of costs of a constant 60/40 split to a variable split that begins at 60/40 and rises to 100/0 in the final round. This analysis shows that making the last round of competition winner-take-all considerably lowers the minimum cost to the government in each instance because it expands the number of non-dominated bidding options for the two companies to include lower bids in later rounds. A company may actually bid at a loss in early rounds in order to win more units than its competitor, progress further down the learning curve, and be at a greater cost advantage to win all remaining units in the final round.

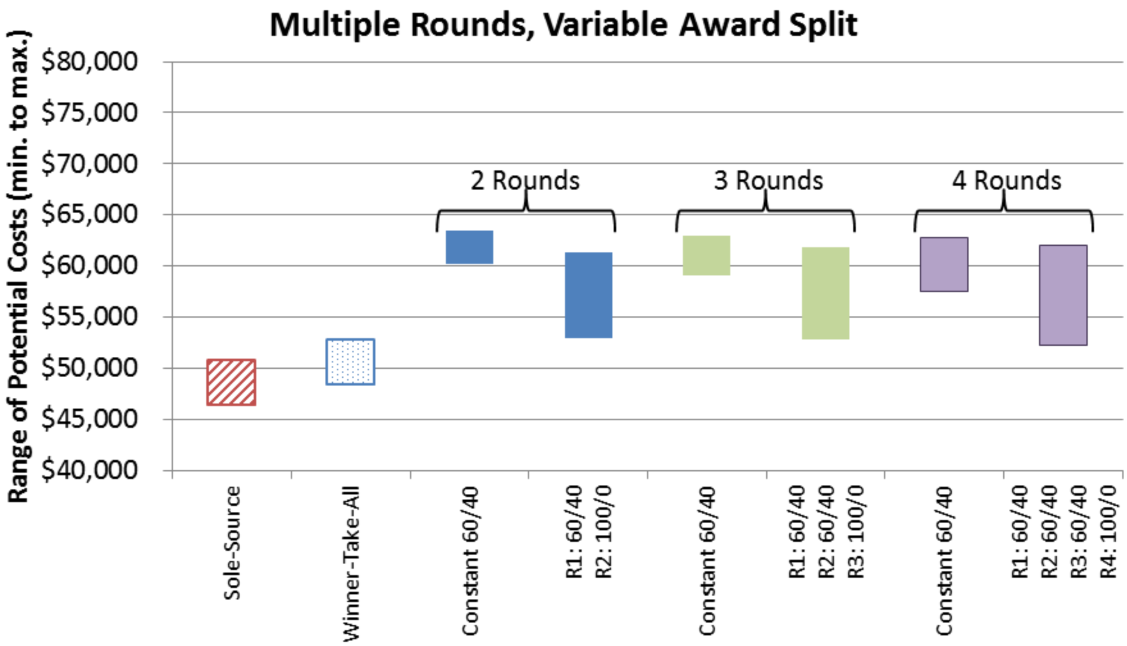


Figure 6: Multiple Rounds of Competition with Variable Award Split

<u>Case 6: Multiple Rounds, Variable Award Split and Variable Quantity in Each Round</u>

The sixth case adds one more dimension to competition by varying the number of units awarded in each round. The examples shown in Figure 7 use a 60/40 split and award only five units per round initially, and then award all remaining units in the final round with a 100/0 split. This has the effect of raising the stakes of the competition in the final round even higher than under Case 5, and it lowers the range of potential costs significantly. It also makes the result similar to the single-round, winner-take-all competition because the winner of the final round receives the vast majority of the total quantity. For example, in the four-round competition used in this example the company that wins the final round will receive 91 to 94 of the 100 total units awarded, depending on how many of the early rounds it wins. In Case 6, the minimum cost to the government dips slightly below the maximum cost of the sole-source competition. Because the cost ranges overlap, it is possible that these competitions could save the government money relative to the cost of a sole-source award.

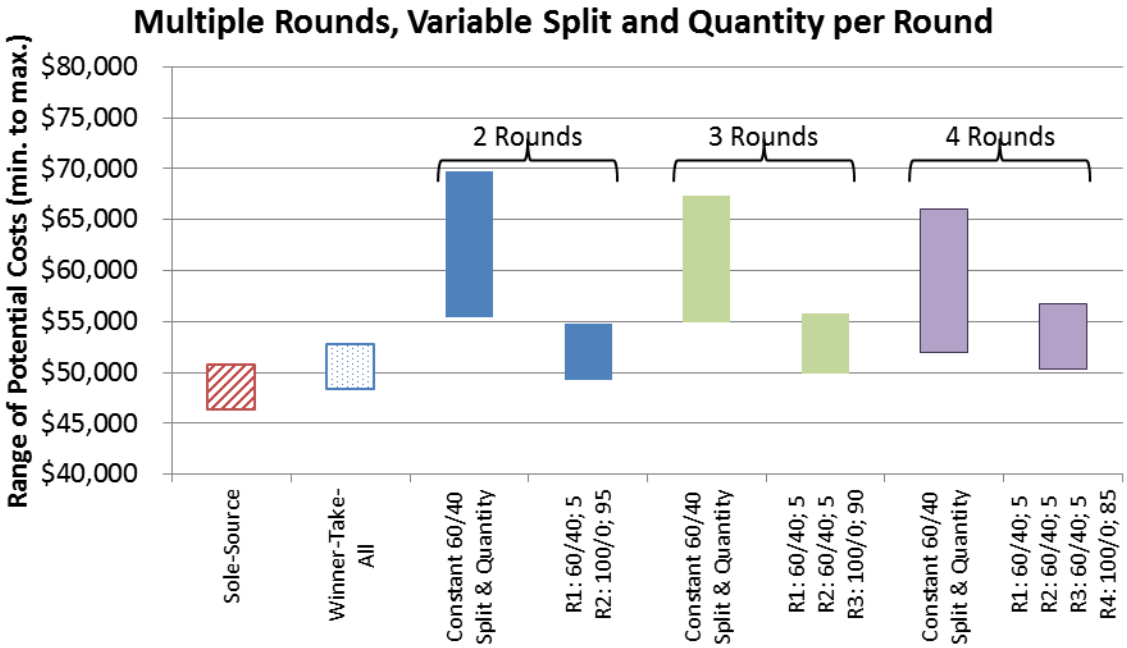


Figure 7: Multiple Rounds of Competition with Variable Award Split and Variable Quantity

Sensitivity to Program-Specific Factors

While the results shown in this analysis are true for the assumptions used, changes in these assumptions would yield different results. To understand when competition offers the potential for savings (i.e., the range of costs from a particular form of competition overlap with the range of costs from a sole-source award), several program-specific factors must be assumed in the model. This section explores how varying program-specific factors, such as learning percent, development cost, first unit cost, and total quantity, affect the results.

Learning Percent

The learning percent varies for different industries and different types of manufacturing processes. A key factor affecting the learning percent is the amount of automation involved; the more automation (and thus fewer people) involved in the manufacturing process, the less opportunity there is for learning and the higher the learning percent. While humans get better with practice, automation offers consistency. While the preceding analysis assumed a learning percent of 85, it is reasonable to expect that the learning percent could vary from 80 to 90 percent depending on the industry and the application (Stewart & Wyskida, 1987, pp. 178-180).

The analysis was repeated using a learning percent of 80 and 90 to show how the results would differ. The variation in learning percent has a notable effect on the results in Cases 5 and 6, as shown in Figure 8 and Figure 9. When the award split (Case 5) or the award split and quantity (Case 6) are varied by round with a learning percent of 90, the range of cost in each of the variations tested overlaps with the sole-source case. With a learning percent of 80, varying the award split and quantity per round causes the range of costs to diverge from the sole-source case. This is because a lower learning percent means learning happens faster and creates a greater advantage for the company that wins the first round of

competition. Thus, it limits the ability of the company that loses the first round to compete effectively in later rounds.

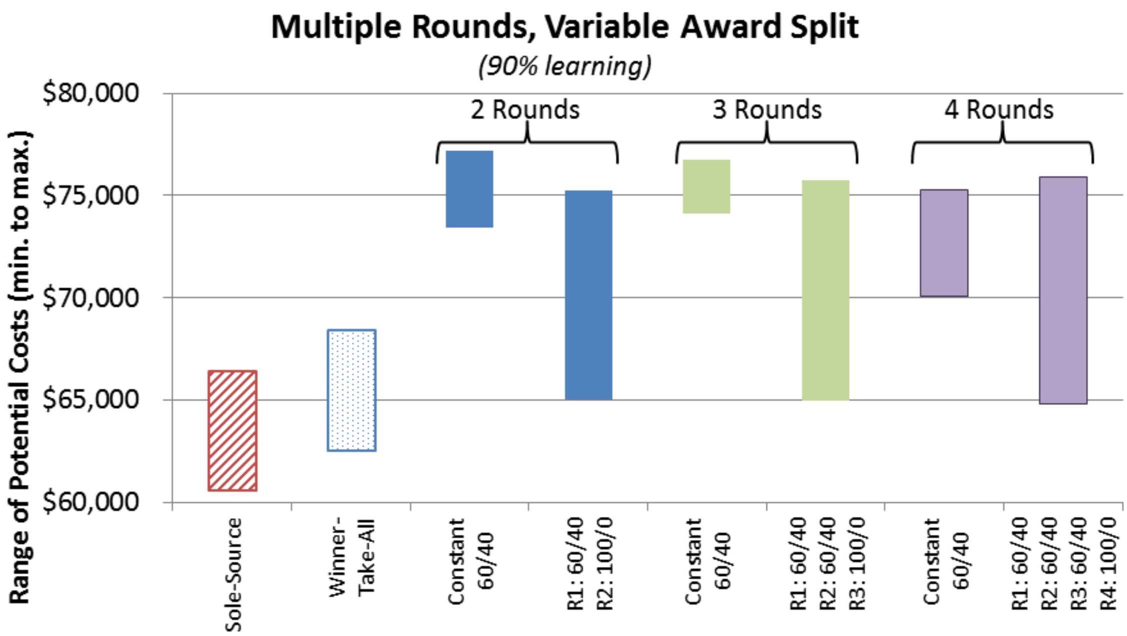


Figure 8: Case 5 Example with Learning Percent of 90

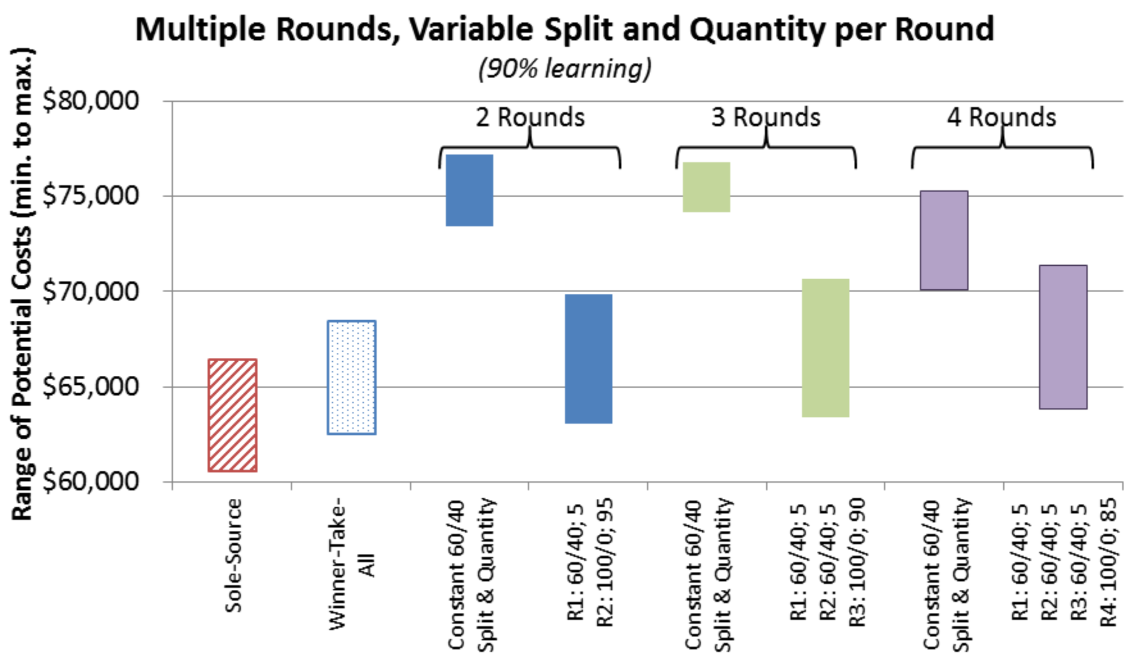


Figure 9: Case 6 Example with Learning Percent of 90

Development Cost and First Unit Cost

The fixed development and first unit costs assumed have a more obvious effect on the results, essentially scaling the development and production costs, respectively. The development cost is additive to the total

cost to the government. For example, the primary difference between the winner-take-all competition and the sole-source case is that two development contracts are used in the winner-take-all competition, increasing its costs by the amount of one development contract. The first unit cost is the starting point from which the learning curve begins and the basis for calculating the total production cost. If the first unit cost doubles, the total cost of production doubles.

The ratio of development cost to first unit cost is an indicator of how much of the total program cost is due to development versus production. The preceding analysis assumed a development cost of $2,000 and a first unit cost of $1,000 for a ratio of 2:1. A higher ratio would mean a greater share of the costs are due to the upfront development work required, which makes the added cost of funding two contractors more difficult to recoup through competition. A higher ratio also means the production work—the source of any potential savings from competition—is a smaller share of the overall program cost. Thus, a higher development cost or lower first unit cost will make competition less attractive. Conversely, a lower development cost or higher first unit cost will make competition more attractive.

Figure 10 shows how the results would change if the development cost is doubled to $4,000 and the first unit cost is cut in half to $500, with all other factors held constant. The minimum cost of the two-round competition with a variable split and variable quantity goes from being 3 percent less than the maximum cost of the sole-source award (a slight overlap of the two ranges) to being 8 percent higher (no overlap).

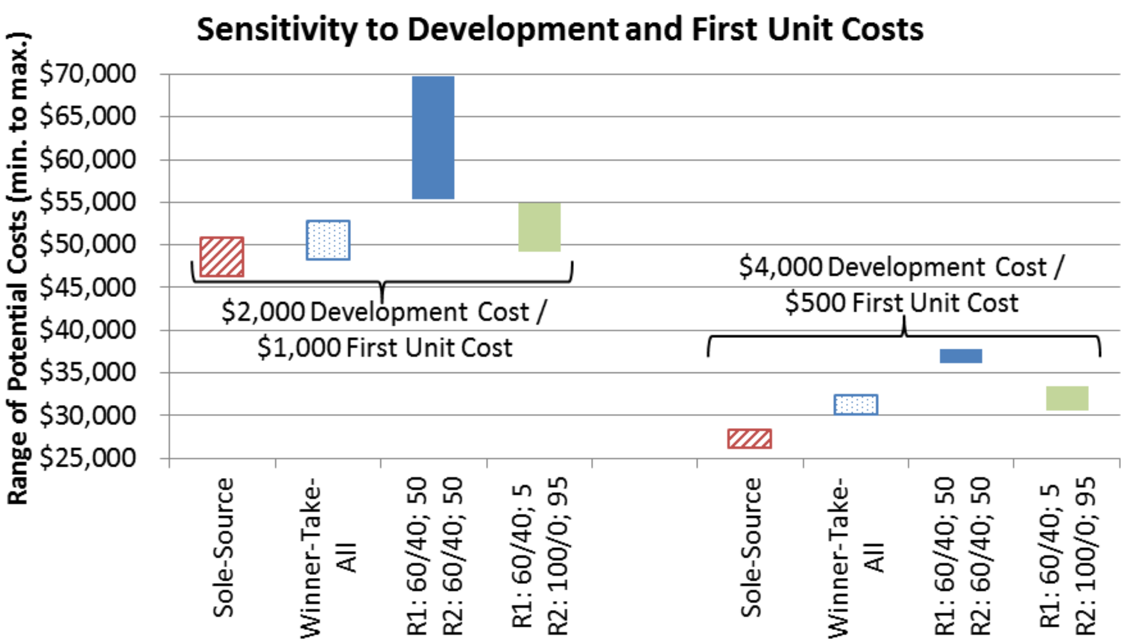


Figure 10: Sensitivity of Results to Changes in Development and First Unit Costs

<u>Quantity</u>
Another important factor in the analysis is the total quantity being acquired. The example in the preceding analysis uses a quantity of 100, which is a relatively small number for production purposes but similar to the quantities in which DoD procures major weapons platforms, such as ships and bombers. DoD procures other systems, like radios and ground vehicles, in much larger quantities. The development costs of a system are essentially constant regardless of the number of units procured because the first unit

still has to be developed. As more units are procured, the total cost continues to rise, albeit at a progressively slower rate as the unit cost declines due to the learning curve effect. As more of the overall costs are shifted into production from a larger buy, competition becomes more attractive. Figure 11 shows how the results change if the quantity is increased from 100 to 1,000 with all other factors held constant. The minimum cost of the two-round competition with a variable split and variable quantity goes from being 3 percent less than the maximum cost of the sole-source award to being 7 percent less.

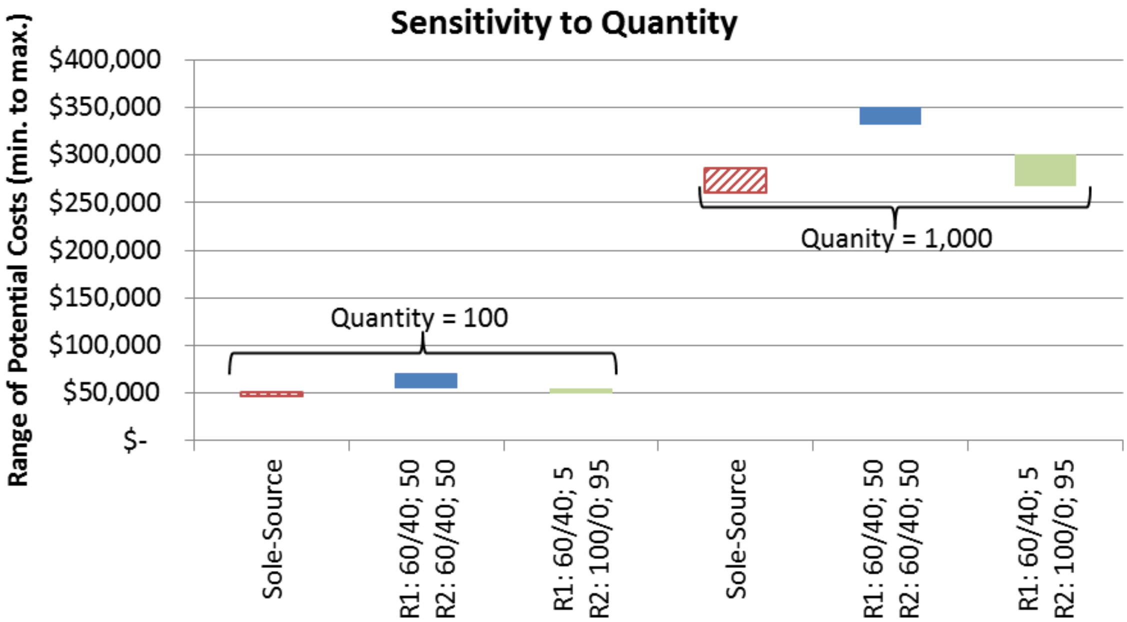


Figure 11: Sensitivity of Results to Increasing Quantity from 100 to 1,000

Considerations Other Than Cost

While reducing the acquisition cost of a weapon system should be a major factor in developing an acquisition strategy, it is not the only factor to consider. The long-term cost of operating and sustaining (O&S) a weapon system is also an important consideration. O&S costs can be higher if two sets of equipment designed and built by different companies must be maintained, since different tooling and training may be required. But if some or all of the maintenance is contracted out, competition for maintenance work could help promote efficiency and lower costs—especially if the original manufacturers can compete to maintain not only the systems they built but their competitor's as well.

The potential impacts on the industrial base should also be a consideration in selecting an acquisition strategy. While awarding a contract on a sole-source or winner-take-all basis may reduce costs, it could also knock competitors out of the marketplace. In some sectors of the industrial base, losing a single company would mean a significant reduction in overall industrial capacity and could effectively eliminate the possibility of competition in future acquisitions. While this may be unavoidable in some sectors of the industrial base given future budget constraints, the Department should make such decisions with a good understanding of the long-term consequences and risks. The additional cost of competition may at times be a price worth paying.

Operational risks should also be a consideration in developing an acquisition strategy. As major weapon systems become more expensive and more capable, the number of different types and the total quantity of weapon systems procured is steadily declining. For example, the three variants of the F-35 Joint Strike Fighter will one day make up the vast majority of tactical fighters across all the Services. While there are notable differences among the three variants of the F-35, many of the components and subsystems are identical. The engine and software, for example, are common across all three variants. If a design flaw were uncovered in the engine, it could result in the grounding of nearly the entire U.S. fleet of tactical fighters. Likewise, if the software were compromised through a cyber-attack or an accidental error in programming, a major component of U.S. power projection could be at risk.

Innovation is another factor that should be considered. An acquisition strategy that continues the competition over several rounds can induce contractors to continue innovating their designs and manufacturing processes. The increase in innovation resulting from competition cannot always be measured or modeled, particularly if the innovation takes the form of improved capabilities in the system being produced. Innovation in the manufacturing process, however, can be factored into the model by a reduction in the learning percent relative to the sole-source or winner-take-all cases.

Conclusion

While competition has an intuitive appeal as a way to drive down costs in defense acquisitions, this is not always the case. As this paper shows, competition can, under certain circumstances, drive up acquisition costs by incentivizing contractors to bid higher. The competitive pricing model presented in this paper allows acquisition professionals to "game" how companies are incentivized to bid under different conditions. The key question for acquisition professionals is not when does competition make sense, but rather when does it not make sense. That is, when can competition be ruled out as a viable option for reducing acquisition costs? And when competition does have the potential to reduce costs, how can it be properly structured to increase the likelihood that savings are realized?

Several factors must be taken into account when determining if competition has the potential to reduce costs relative to a sole-source or winner-take-all award. The structure of the competition, specifically the number of rounds of competition and the award split and quantity awarded in each round, is a determining factor in whether a competition has the potential to reduce costs. The potential savings also depend on several program-specific factors, namely the rate of learning in production, the relative costs of development and the first unit of production, and the total quantity of items being procured.

This paper provides a quantitative model for understanding the range of effects competition can have on acquisition costs—some of which can be counterintuitive. It provides a way to estimate in advance if the competitive pressure between contractors could produce sufficient savings to overcome the added cost of additional development work and reduced learning from splitting the award between two production lines. Rather than providing general rules for when competition is appropriate, it provides a methodology that can be applied to a specific program. Using this approach, acquisition professionals can explore different ways of structuring a competition for a specific program and use this understanding to help inform sound acquisition strategies.

Author Biography

Todd Harrison is the Senior Fellow for Defense Budget Studies at the Center for Strategic and Budgetary Assessments. Mr. Harrison joined CSBA in 2009 from Booz Allen Hamilton, where he supported clients across the Department of Defense, assessing challenges to modernization initiatives and evaluating the performance of acquisition programs. He previously worked in the aerospace industry developing advanced space systems and technologies and served as a captain in the U.S. Air Force Reserves.

Since joining CSBA, Mr. Harrison has authored a number of publications on trends in the overall defense budget, modernization initiatives, the defense industrial base, military personnel costs, and the cost of the wars in Iraq, Afghanistan and Libya. He frequently contributes to print and broadcast media and has appeared on CNBC, CNN, NPR, Al Jazeera English, and Fox News. He has been a guest lecturer for a number of organizations, including Harvard's Kennedy School of Government, the U.S. Army's School of Advanced Military Studies (SAMS), and the National Defense University. Mr. Harrison is a member of the Council on Foreign Relations.

He is a graduate of the Massachusetts Institute of Technology with both a B.S. and an M.S. in Aeronautics and Astronautics. Mr. Harrison combines his budgetary, programmatic, and engineering experience with a strong background in systems analysis to lead the Budget Studies program for CSBA.

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The Effects of Competition on Defense Acquisitions: *A Game Theory Approach*

Todd Harrison

September 18, 2012

Is Competition a "Cure-All?"

Former Secretary of Defense Robert Gates:

"Competition is a major source of productivity in the defense industry, as it is in commercial industry."

Former Under Secretary of Defense Ashton Carter:

"Real competition is the single most powerful tool available to the Department to drive productivity."

Weapon Systems Acquisition Reform Act of 2009:

Requires DoD to use acquisition strategies that *"ensure competition, or the option of competition, at both the prime contract level and the subcontract level."*

But the "cure" of competition can sometimes be worse than the disease.

Defense Industry Not a Typical Free Market

- In a traditional free market:
  - Many buyers and sellers
  - Buyers exert control over sellers by patronage
  - As demand falls, prices fall
- Defense is more like a monopsony-duopoly or bi-lateral monopoly
  - Few (if any) other buyers for many of the major weapon systems DoD procures
    - Stealthy aircraft, nuclear submarines, specialized comms equipment
    - Where there are other potential customers (allies and partner nations) quantities are lower and must be approved by U.S. Government
  - Limited number of vendors (primes and subs) capable of producing the systems required
- DoD is not a typical customer
  - Prices are often based on the costs incurred by contractors, not supply and demand
  - As demand falls, unit costs often rise
  - DoD is not just a customer but also a regulator of the industry

Why Competition Does Not Always Reduce Costs

1. Added cost of redundant development work
   - As the only customer for many systems, DoD must pay (directly or indirectly) for two or more contractors to develop the same system
   - Even if a “build to print” approach is used, DoD must still pay for the development of more than one production line
   - Allows for a competition once development work is complete
     - DoD can down-select to a single vendor for production, which effectively ends the competition and grants the winner a monopoly
     - Or can split the award between competing contractors to maintain the prospect of future competition

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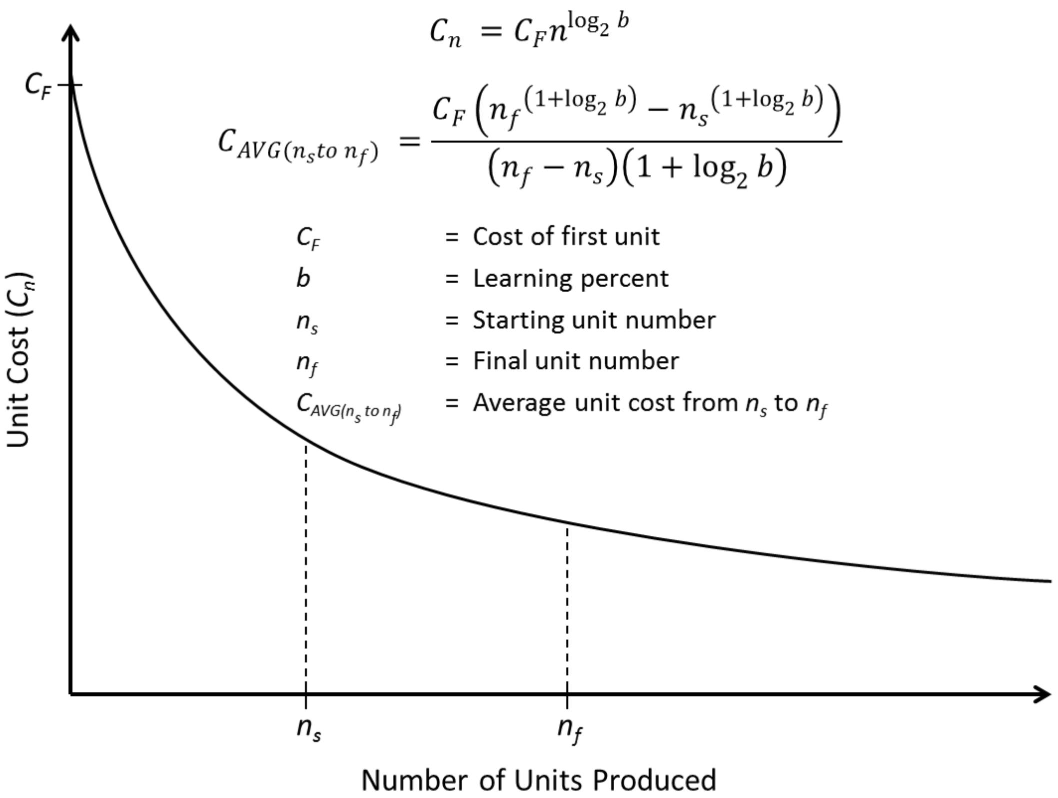
Why Competition Does Not Always Reduce Costs

2. Learning curve effect
   - A split award means neither contractor receives as many orders and thus neither progresses as far down the learning curve
   - Cost of each unit will not decline as much as it would if one company were building everything



Why Competition Does Not Always Reduce Costs

3. Structure of the competition itself
   - Dual-source, winner-take-all, split award, etc.
   - Can the additional costs from redundant development work and reduced learning be offset by competitive pressure? It depends…
   - Historical analysis is insufficient
     - To calculate the savings from competition, one needs to know what would have happened had competition *not* been used
     - Does not account for differences in the structure of the competition, such as award split and quantity of units being procured

Base Case: Sole Source Award

- Use a sole source award for comparison, ranging from zero profit to a maximum assumed profit, P_{max}

$$
\begin{aligned}
C_{TOTAL} &= C_{DEV} + Q \times C_{AVG\ (0\ to\ Q)} \\
&= \$2{,}000 + 100 \times \left(\frac{\$1{,}000 \times 100^{(1+\log_2 0.85)}}{100 \times (1+\log_2 0.85)} \right) = \$46{,}372
\end{aligned}
$$

$$
\begin{aligned}
C_{TOTAL} &= C_{DEV} + Q \times (1 + P_{max}) \times C_{AVG\ (0\ to\ Q)} \\
&= \$2{,}000 + 100 \times (1 + 0.1) \times \left(\frac{\$1{,}000 \times 100^{(1+log_2 0.85)}}{100 \times (1+log_2 0.85)} \right) = \$50{,}809
\end{aligned}
$$

Competitive Pricing Model

- Uses game theory to model how companies would bid in a competition
- Takes into account development costs and learning curve effect
- Models how companies would be incentivized to bid depending on:
  - Number of rounds of competition
  - Split in award between contractors (or winner-take-all)
  - Quantity of units procured
- Assumed parameters can also be varied separately for each company
  - First unit cost
  - Learning percent
  - Max/min profit
  - Initial development cost
  - Total quantity of units procured

First Unit Cost (C_F)	Learning Percent (b)	Maximum Profit (P_{max})	Minimum Profit (P_{min})	Total Quantity of Units Procured (Q)	Initial Development Cost (C_{DEV})
$1,000	85%	10%	-10%	100	$2,000

Assumptions in Model

- Two competitors with virtually identical products (form, fit, function approach)
- Both companies have perfect information about their own costs, such as first unit cost and learning percent, as well as their competitor's underlying costs
- Companies bid in secret so that one does not know how the other is bidding in the current round, but do know how their competitor bid in previous rounds
- Companies try to maximize net profit from all rounds of competition
- Each company has a limited set of six price points to select from in each round, determined dynamically in each round for each company
- Unit cost is assumed not to vary with production rate or economies of scale, will tend to make competition look more favorable (lower cost) than it should
- Learning percent assumed constant throughout the production run
- Company A wins all ties
- Uses iterated elimination of strictly dominated strategies

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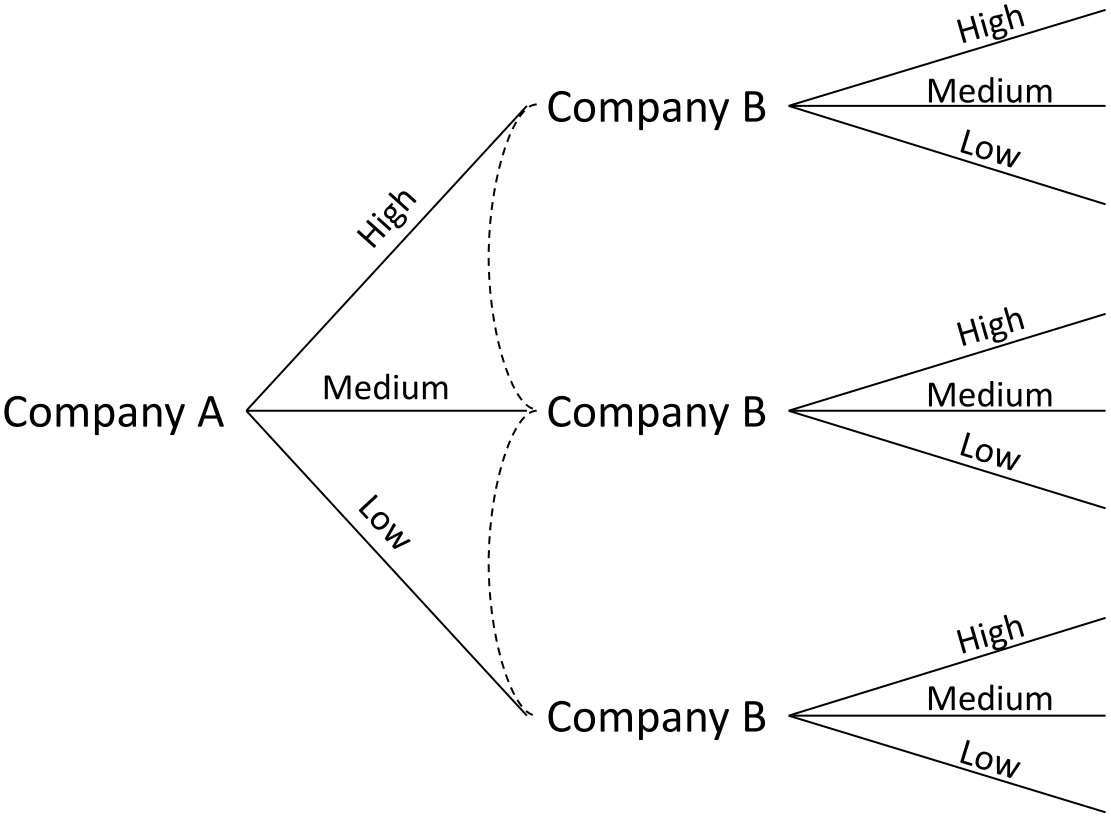
Example: Single Round, Winner-Take-All



	Company A Profit	Company B Profit	Total Cost to Government
	$4,437	$0	$52,808
	$0	$0	$48,371
X	$0	-$4,437	$43,934
	$0	$0	$48,371
	$0	$0	$48,371
X	$0	-$4,437	$43,934
X	-$4,437	$0	$43,934
X	-$4,437	$0	$43,934
X	-$4,437	$0	$43,934

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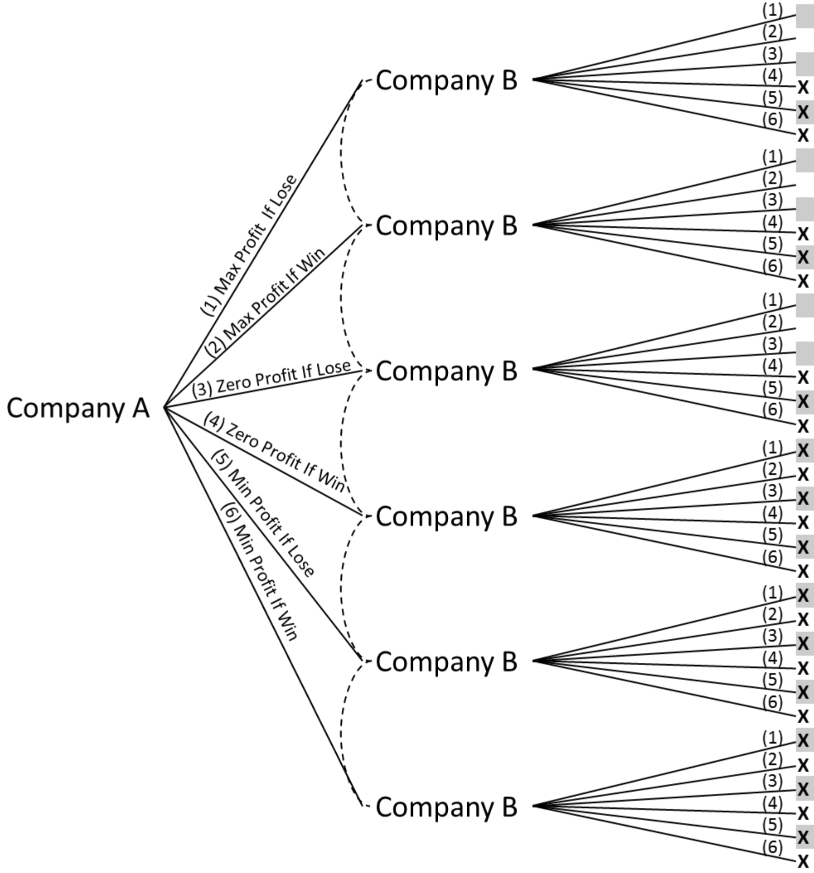
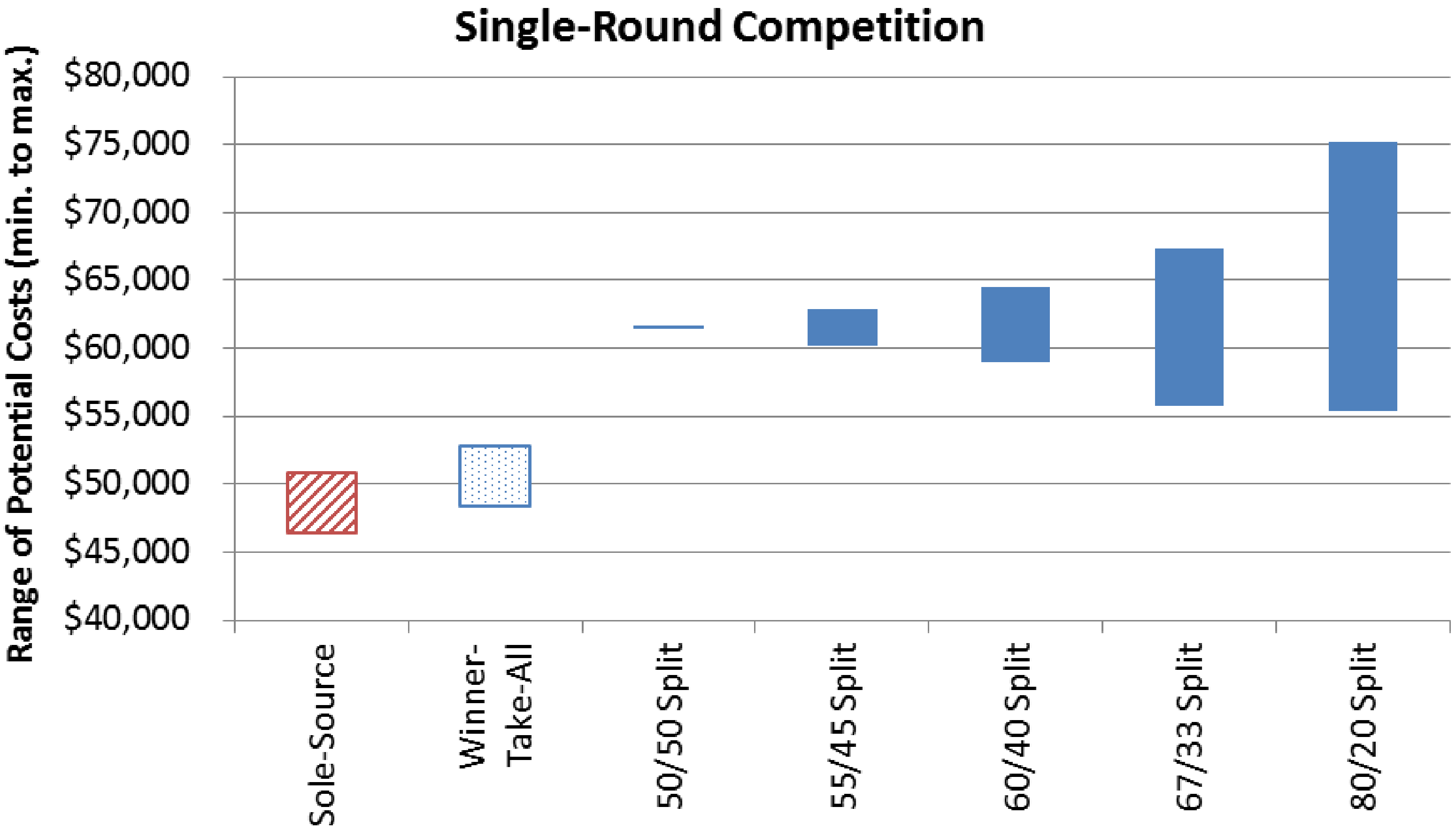
Example: Single Round, 60/40 Split Award



	Company A Profit	Company B Profit	Total Cost to Government
	$6,293	$2,200	$64,506
	$2,200	$3,001	$61,213
	$2,200	$2,993	$61,205
X	$2,200	$0	$58,212
X	$2,200	-$307	$57,905
X	$2,200	-$3,001	$55,211
	$3,001	$2,200	$61,213
	$3,001	$5	$59,019
	$5	$2,993	$59,011
X	$5	$0	$56,018
X	$5	-$307	$55,710
X	$5	-$3,001	$53,016
	$2,993	$2,200	$61,205
	$2,993	$5	$59,011
	$2,993	$0	$59,005
X	$0	$0	$56,012
X	$0	-$307	$55,705
X	$0	-$3,001	$53,011
X	$0	$2,200	$58,212
X	$0	$5	$56,018
X	$0	$0	$56,012
X	$0	-$1,995	$54,017
X	-$1,995	-$307	$53,710
X	-$1,995	-$3,001	$51,016
X	-$307	$2,200	$57,905
X	-$307	$5	$55,710
X	-$307	$0	$55,705
X	-$307	-$1,995	$53,710
X	-$307	-$2,200	$53,505
X	-$2,200	-$3,001	$50,811
X	-$3,001	$2,200	$55,211
X	-$3,001	$5	$53,016
X	-$3,001	$0	$53,011
X	-$3,001	-$1,995	$51,016
X	-$3,001	-$2,200	$50,811
X	-$3,001	-$3,996	$49,015

- Only 9 of 36 outcomes are non-dominated
- Each company only bids options 1, 2, or 3
- Total Cost could range from $59,005 to $64,506
- Compares to range from sole source award of $46,372 to $50,809

Comparison of Award Split for Single Round



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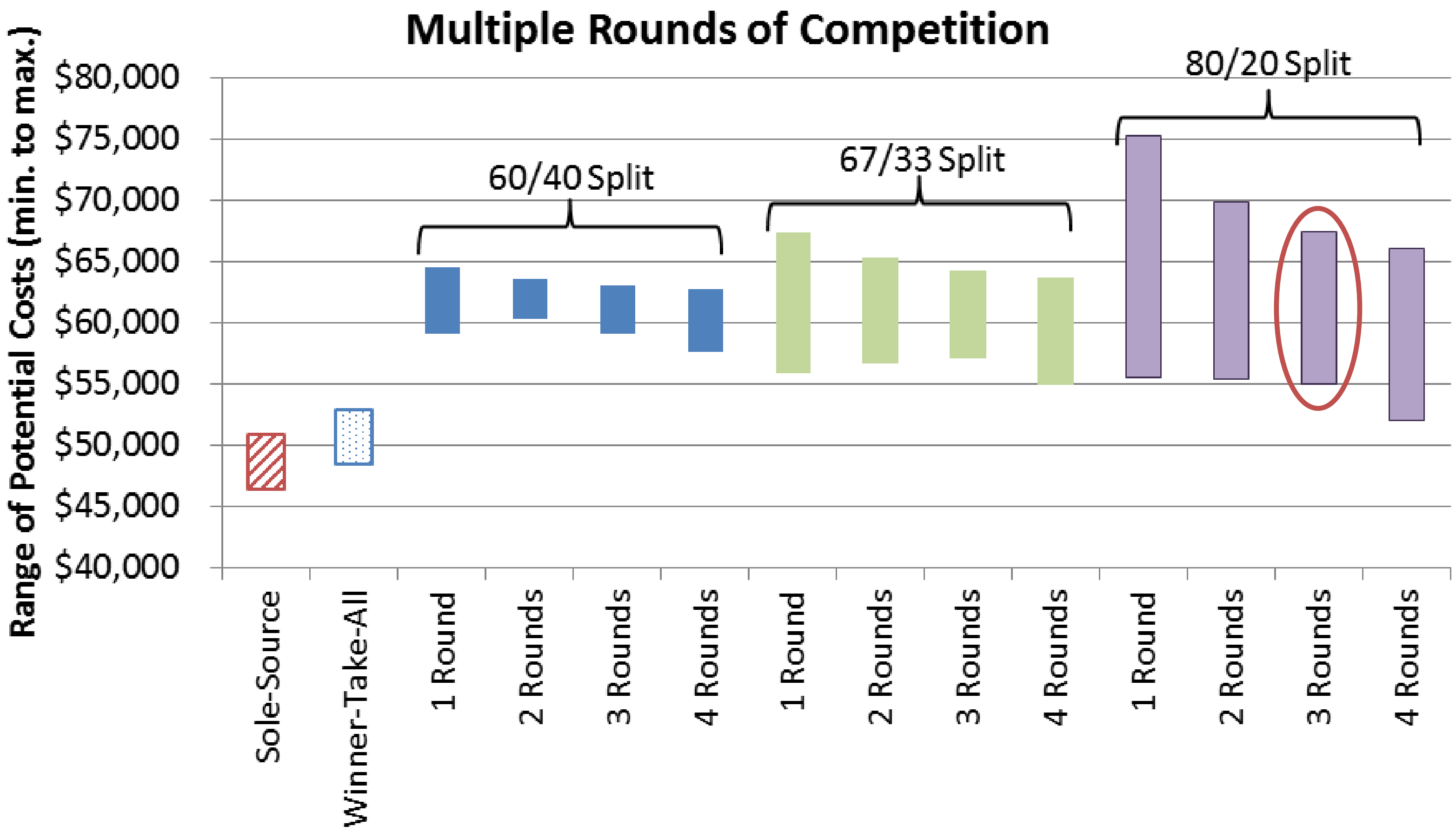
Example: Multiple Rounds of Competition

- Same principles and assumptions apply
- Calculates become longer and more complex
  - Single round: 36 possible outcomes, <1 second
  - Two rounds: 1,296 possible outcomes, ~1-2 seconds
  - Three rounds: 46,656 possible outcomes, ~1-5 minutes
  - Four rounds: 1,679,616 possible outcomes, ~1 hour
  - Five rounds: 60,466,176 possible outcomes, multiple days

Comparison of Award Split for Multiple Rounds



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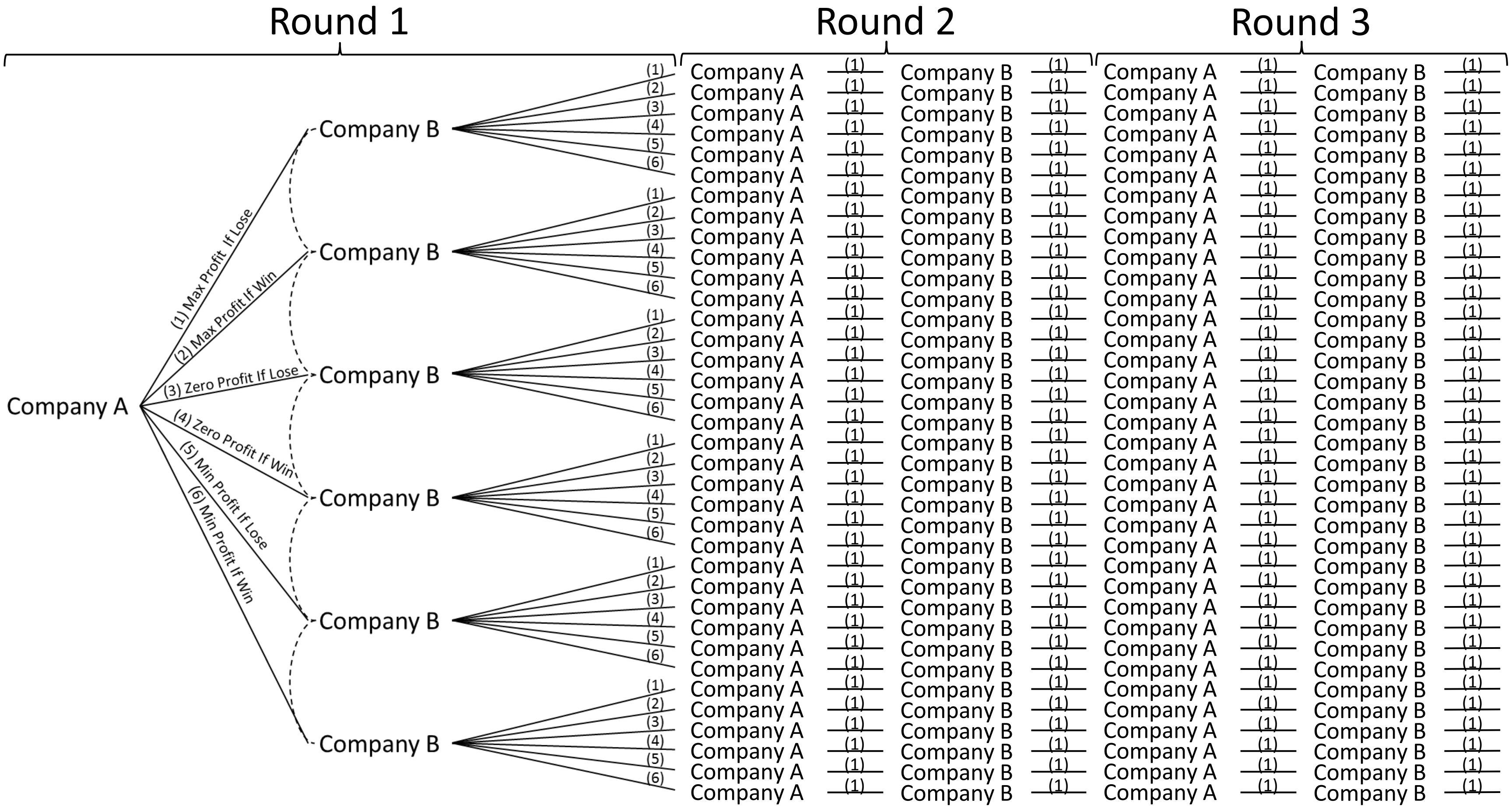
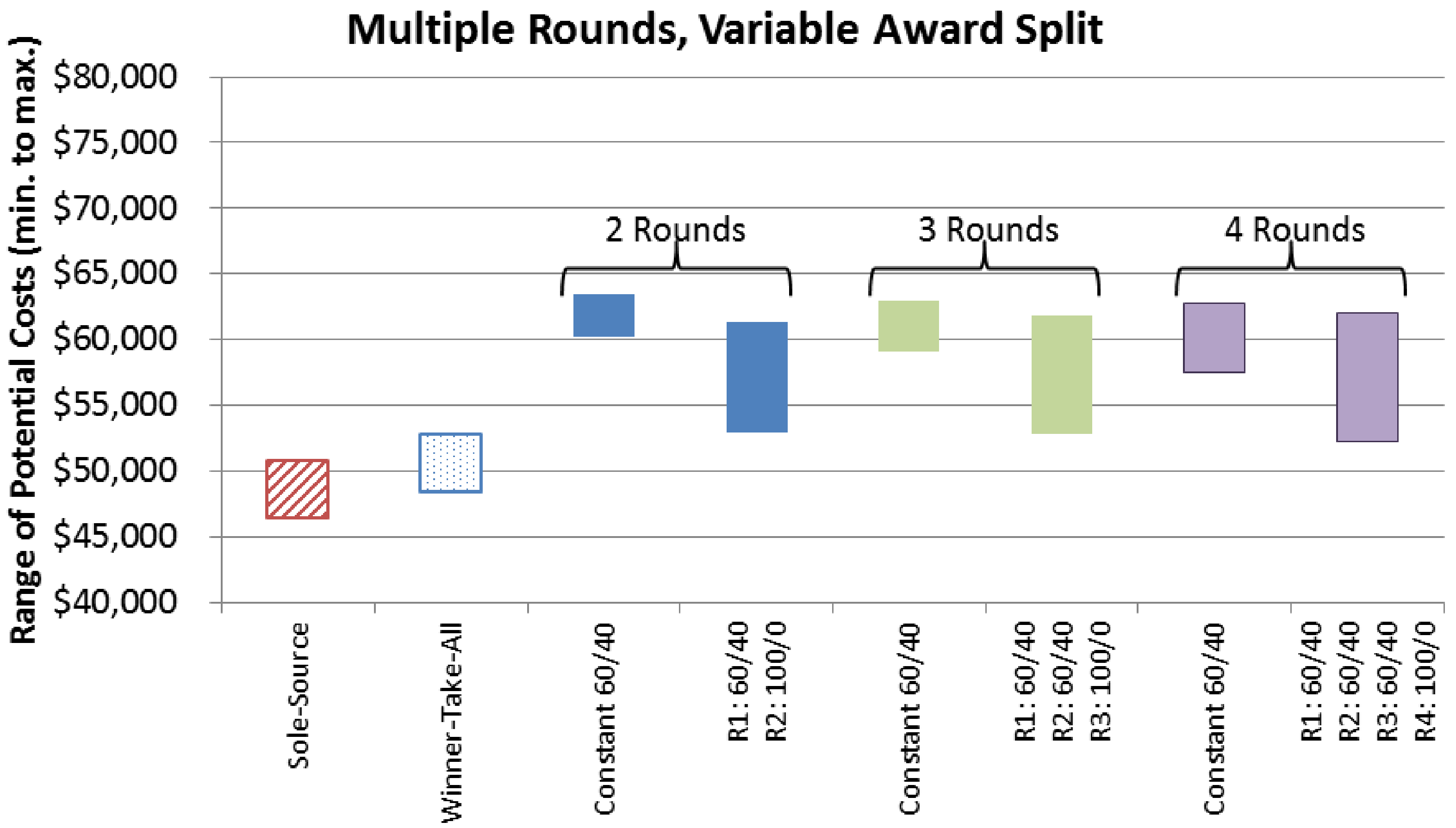
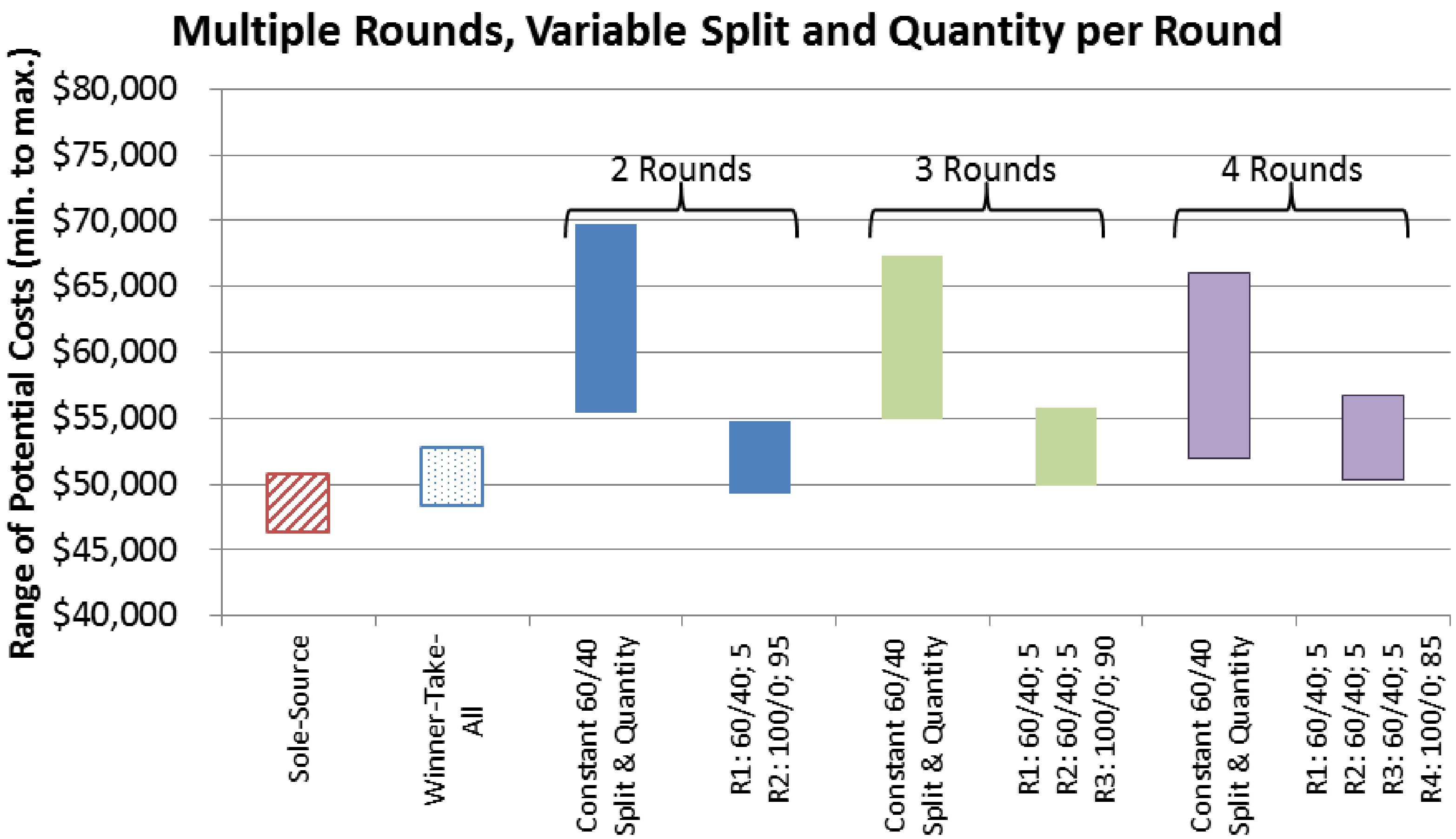
Three-Round, 80/20 Award Split



Variable Award Split by Round



Variable Award Split and Quantity



Sensitivity to Assumptions

- A higher learning percent tends to make competition more favorable in multi-round competitions
- Higher development cost or lower first unit cost will make competition less attractive
  - Higher ratio means a greater share of total cost due to development work—more difficult to recoup through competition
  - Higher ratio also means production work, the source of any potential savings from competition, is a smaller share of total cost
- As the total quantity of units procured rises, more costs are shifted into production and competition is more attractive

Considerations Other Than Cost

- Long-term O&S costs
  - Can be higher if two different sets of equipment must be maintained
  - Competition for maintenance work could promote efficiency and lower costs
- Industrial base
  - Awarding a sole-source or winner-take-all contract could permanently knock competitors out of the marketplace
  - Would reduce overall industrial capacity and limit future competition
- Operational risks
  - Being dependent on a single system or subsystem creates operational risks if a design flaw is uncovered
- Innovation
  - Sustained competition over multiple rounds can induce contractors to continue innovating their designs and manufacturing processes
  - Cannot always be measured or modeled

Conclusions

- Competition has an intuitive appeal but does not always drive down costs
- Certain competition structures can actually drive up acquisition costs by incentivizing contractors to bid higher
- Key questions for designing an acquisition strategy:
  - What is the best way to structure a competition to better incentivize contractors and reduce costs?
  - When can competition be ruled out as a viable option for reducing costs?
- Answer depends on program specific factors
- The model presented provides a way to explore different structures and to help inform sound acquisition strategies